J. Agronomy & Crop Science **191**, 210—217 (2005)

ISSN 0931-2250

Crop/ Stress Physiology

Department of Agriculture, University of Maryland Eastern Shore, MD, USA

Effect of Water Stress on the Yield of Cowpea (*Vigna unguiculata* L. Walp.) Genotypes in the Delmarva Region of the United States

R. B. Dadson, F. M. Hashem, I. Javaid, J. Joshi, A. L. Allen, and T. E. Devine

Authors' addresses: Dr R. B. Dadson, Dr F. M. Hashem, Dr I. Javaid (corresponding author; e-mail: iqbal_javaid3@hotmail.com; ijavaid@umes.edu), Dr J. Joshi and Dr A. L. Allen, Department of Agriculture, University of Maryland Eastern Shore, Crop Research and Aquaculture Building, 30921 Martin Court, Princess Anne, MD 21853 1299, USA; Dr T. E. Devine, Sustainable Agricultural Systems Laboratory, USDA, ARS, Beltsville, MD 20705, USA

With 3 tables

Received April 14, 2004; accepted June 9, 2004

Abstract

Drought is an important yield-reducing factor for corn and soya bean which are the two major crops in the Delaware, Maryland and Virginia (Delmarva) region of the United States. Cowpea (*Vigna unguiculata* L. Walp.) is primarily grown in drier regions of the world where it is one of the most drought-resistant food legumes. Field experiments were conducted in which 10 genetically diverse cowpea genotypes were evaluated for adaptability to the Delmarva area. The cowpea genotypes were grown in rain-out shelters under non-water-stressed and water-stressed conditions. The results showed that under non-water-stressed conditions cowpea genotypes California Blackeye 5, Champion and Mississippi Silver gave higher seed yields, while genotypes White Acre, Six Week Browneye and Texas Cream 8 provided lower seed yields. Genotypes California Blackeye 5 and Champion gave comparatively better seed yields under water-stressed conditions. California Blackeye 5 was the highest seed-yielding genotype under both water-stressed and non-water-stressed conditions. The highest biological yield under non-water-stressed conditions was given by genotypes Two Crop Brown, White Acre and Elite, whereas under the water-stressed condition genotypes Texas Cream 8, California Blackeye 5, and Mississippi Silver gave higher biological yield. Genotypes Quickpick Pinkeye and Elite were identified as early maturing genotypes. The harvest index (HI) varied significantly among genotypes, with Texas Cream 8 having the lowest HI. Cowpea genotypes which gave higher seed yield under water-stressed conditions could play an important role in sustaining crop production in the Delmarva region.

Key words: biological yield — Delmarva region — drought tolerance — earliness — seed yield — *Vigna unguiculata*

Introduction

Cowpea (*Vigna unguiculata* L. Walp.) is grown on about 7–8 million hectares in warm to hot regions of the world (Ehlers and Hall 1997, Mortimore et al. 1997) with an annual production of 3 million tons worldwide (Singh et al. 1997). Of the world total production area, Africa accounts for 6 million hectares (Mortimore et al. 1997). Cowpea provides an inexpensive source of protein for many people in different regions of the world (Alghali 1991). In the United States, commercial production extends from 30°N to as far as 40°N latitudes, and experimental plantings have been successful as far north as Minnesota at 45°N latitude (Davis et al. 1986). The San Joaquin Valley of California and the high plains of Texas are the major regions of dry seed cowpea production in the United States. Cowpea seeds are marketed as dry blackeye beans in as many as 30 countries. Total production of cowpea for dry seed harvest in the United States is estimated at 60 000–80 000 acres (Hall et al. 2003). Cowpea is also grown in the south-eastern United States under rain-fed conditions mainly for use as southern peas for canned and frozen products, and for home use as fresh southern peas (Hall et al. 2003). Cowpea is usually better adapted to drought, high temperatures and other biotic stresses compared with other crop plant species (Ehlers and Hall 1997, Kuykendall et al. 2000, Martins et al. 2003). The crop is also tolerant to low soil fertility. Due to its high rates of nitrogen fixation

(Elowed and Hall 1986, Kuykendall et al. 2000, Martins et al. 2003) and effective symbiosis with mycorrhizae (Kwapata and Hall 1985), it does not deplete the natural reserves of soil nitrogen and phosphorus, and many experimental findings confirm that soil nitrogen levels increase by about 40–80 kg N ha^{-1} following cowpea in rotation (Quin 1997). Cowpea also has the ability to tolerate both acid and alkaline soil conditions (Fery 1990), and the crop is responsive to favourable growing conditions (Ehlers and Hall 1997). Many cultivars of cowpea are, however, damaged by drought and high temperatures, especially during floral development. The combination of high temperature, drought and long days can slow down or inhibit floral bud development, resulting in few flowers being produced and substantially reduced cowpea productivity (Nielsen and Hall 1985, Dow El-Madina and Hall 1986, Patel and Hall 1990).

Selection for early flowering and empirical yield testing of breeding lines under dry production conditions has been used successfully to develop cowpea cultivars adapted to low rainfall areas (Hall and Patel 1985, Cisse et al. 1997). Heat-tolerant breeding lines developed at the University of California, Riverside, have produced more than twice the yield of commercial cultivars in field trials conducted in the Coachella Valley of California during the summer season, a very hot environment in the low elevation desert (Ismail and Hall 1998). Stability in yields of agronomically acceptable cultivars is generally regarded as the ultimate goal in cowpea improvement and a cornerstone in achieving sustainability (Oghiakhe et al. 1995). One way to obtain this is to identify genotypes with adequate levels of resistance to drought, heat and other stresses. There is a need for cowpea cultivars, which are more tolerant to water deficit or more efficient in their water use (Anyia and Herzog 2004). However, progress in breeding cultivars for dry environments has been slow (Hall et al. 1997).

Cowpea possesses high yield plasticity under diverse environments, and could alleviate the economic hardships of farmers in case of severe drought and heat. With its high nutrient content, for example 25 % protein (Quin 1997), cowpea may be regarded as a very nutritious food legume for many ethnic communities who use it in their diets. Progress can be made in breeding cowpea cultivars with phenologies and plant habits that are suited to specific target production zones and crop product utilization (Hall et al. 2003).

The Delmarva region is a relatively flat peninsula encompassing portions of the states of Delaware, Maryland and Virginia. It is bordered on the east by the Atlantic Ocean and on the west by the Chesapeake Bay and lies within the longitude 75°2′W to 75°47′W and latitude 36°31′N to 39°50′N. Surface elevations range from zero to 45.6 m with the majority of land area being $<$24.3 m above sea level. This region has a humid continental type of climate with an average annual rainfall 1092 mm (sometimes as low as 610 mm $year^{-1}$). The Delmarva region experiences severe drought and elevated summer temperatures that sometimes reach as high as 44 °C. Most of the Delmarva soil is Othello, sedimentary, acidic soil, and low in natural plant nutrients. The soils range in texture from sandy to sandy loam (USDA 1978).

The yields of corn and soybean in the Delmarva region are lower than the US national average (USDA 1996, Wilcox 2004) due to frequent drought in the growing season and the drought-prone sandy-to-silt loam soils in the region. Drought during flowering and seed filling stages of the two major crops, corn and soya bean, significantly limits crop productivity in this area. Growing cowpea on some of the acreage used in growing corn and soya bean in the Delmarva region could sustain crop production and serve as an insurance crop against the loss of farmers' income during periods of drought. Therefore, field experiments were conducted to identify cowpea genotypes that are early maturing, drought tolerant, and possess high stable seed and biological yield, especially under the Delmarva environmental conditions.

Materials and Methods

Two field experiments were conducted at the Agricultural Experimental Research Farm, University of Maryland Eastern Shore, Princess Anne, Maryland, in 2001 and 2002. Physical and chemical analyses of the soils were conducted at the Soil Testing Laboratory of the University of Maryland College Park, Maryland. The soil texture of both experimental sites was silt loam. The results of the physical analyses of the soils for experiments 1 and 2 showed content of sand as 57 and 64 %, silt as 27 and 22 %, clay as 16 and 14 %, and CEC as 4.73 and 4.59 respectively. The chemical analyses results of the soils were: Mg: 73 and 89 kg ha^{-1}, P: 114 and 172 kg ha^{-1}, K: 70 and 91 kg ha^{-1}, Ca: 35 and 41 kg ha^{-1}, OM: 2.4 and 2.3 %, NO_3-N: 1.8 and 6.60 ppm, and the pH: 5.3 and 6.1 for experiments 1 and 2 respectively. Ten diverse cowpea genotypes, obtained from Tasso Production Limited, Texas, were included in the experiments (Table 1). Both experiments were conducted in a split-plot design. The

Table 1: Traits of cowpea genotypes used in this study

Genotypes	Origin	Year of release	Maturity	Growth habit
Quickpick Pinkeye	NA	NA	Early	Erect
Elite	Arkansas Agric. Exp. Res. Station	1978	Medium	Erect
Mississippi Silver	Mississippi Agric & Forestry Exp. Station	1966	Medium	Semi-erect
Six Week Browneye	NA	1980	Early	Bushy
Big Boy	Texas A & M	1969	Late	Bushy
Texas Cream 8	Texas Agric. Res. Station	1952	Early	Semi-erect
White Acre	NA	1965	Late	Prostrate
Champion	Texas Agric. Res. Station	1962	Medium	Bushy
Two Crop Brown	NA	1974	Medium	Bushy
California Blackeye 5	California Agric. Res. Station	1941	Late	Prostrate

Source: Tasso Production Limited, Houston, USA.
NA, information not available.

main plot treatments included non-water-stressed and water-stressed conditions and the subplot treatments consisted of 10 genotypes in both experiments.

Water-stressed treatments consisted of growing plants in rain-out shelters (Wendt et al. 1981) constructed of transparent polyethylene on wooden frame 1.2 m high at the edges, 2.1 m in the centre, 50.0 m long and 5.6 m wide. All sides of the shelter were covered from the soil surface down to 1.0 m deep in the ground with the polyethylene sheets. Eight shelters of similar dimensions were used for the stressed and non-stressed treatments.

In non-water-stressed treatments, soil tension was kept above −0.03 MPa, and in stressed treatments soil moisture was replenished to field capacity using drip irrigation whenever water tension fell below −0.07 MPa. Soil moisture was monitored using a neutron moisture probe from soil cores at 0.3 m depth increments to 1.2 m depth and averaging the moisture content over the four depths. Weeds in all experiments were controlled manually.

The first and second experiments were sown on 14 June 2001 and 9 June 2002 respectively. In both experiments, there were four rows in each plot and each row was 4 m long. The distances between the rows and plants were 0.75 and 0.20 m respectively. Blocks and plots in both experiments were separated by a spacing of 2 m. The experiments did not receive any fertilizer or insecticide treatments.

All field observations and plant samples were obtained from the central two rows of each four row plot. In addition, the central two rows were harvested for seed yield. Both experiments were harvested manually three to four times as soon as they reached a stage of physiological maturity. After harvest, the pods were oven dried at 60 °C for 7 days, threshed, and the seed yield was recorded. In the second experiment (2002), plants of the two middle rows were cut at soil level from all treatments, after seed harvest, to determine the biological yield. The plants were dried in an oven and the dry weight was recorded. Observations on days from emergence to flowering and maturity for each genotype were also recorded in both experiments. Days to flowering was recorded when about 50 % of the plants were at the flowering stage. The maturity groupings of cowpea genotypes were determined according to Singh et al. (1997) as follows: early maturing for genotypes mature in 60–75 days, medium maturing for genotypes mature in 75–90 days, and late maturing for genotypes mature in 90–120 days. The harvest index (HI) was determined as the ratio of grain weight to total shoot biomass (weight of grains, pods, leaves, branches and stem) after drying the samples at 65 °C for 7 days (Ismail and Hall 1998).

Yield data obtained from both experiments were subjected to analysis of variance (ANOVA) with subsequent mean separation obtained using LSD as described by Steel and Torrie (1980).

Results

Effects of water stress on flowering and maturity of cowpeas

Flowering and maturity occurred uniformly across the replications within each cowpea genotype. Days to 50 % flowering varied greatly among cowpea genotypes (Table 2). In 2001, cowpea genotypes California Blackeye 5, Big Boy, Champion, Elite, White Acre and Two Crop Brown flowered 2–3 days earlier under the water-stressed conditions than under non-water-stressed conditions. Genotypes Texas Cream 8, Quick Pinkeye and Mississippi Silver flowered 1–2 days later under water-stressed than non-water-stressed conditions. In 2002, cowpea genotypes California Blackeye 5, Mississippi Silver, Six Week Browneye and White Acre were 2–4 days earlier in flowering when plants were water-stressed compared with the non-water-stressed condition. Genotypes Texas Cream 8, Quick Pinkeye, Big Boy and Champion were 1–15 days later in flowering when plants were grown under watered stressed conditions compared to non-water-stressed conditions.

Table 2: Phenological characteristics of cowpea genotypes under non-water stressed and water-stressed conditions

	Year 2001				Year 2002			
	Non-water-stressed		Water-stressed		Non-water-stressed		Water-stressed	
Genotypes	Days to flowering (50 %)	Days to maturity (50 %)	Days to flowering (50 %)	Days to maturity (50 %)	Days to flowering (50 %)	Days to maturity (50 %)	Days to flowering (50 %)	Days to maturity (50 %)
Quickpick Pinkeye	49	61	50	60	40	65	55	68
Elite	50	65	48	64	47	65	50	65
Mississippi Silver	50	79	52	82	47	70	45	80
Six Week Browneye	60	80	60	80	63	80	60	82
Big Boy	62	82	60	80	55	80	62	82
Texas Cream 8	60	80	61	83	52	85	58	80
White Acre	64	82	62	80	68	85	64	82
Champion	70	91	68	90	69	90	70	90
Two Crop Brown	72	92	70	90	75	95	72	92
California Blackeye 5	78	90	75	89	80	99	76	92

The effect of water treatments on maturity of cowpea genotypes was similar to the effect on days to flowering. Days to full maturity of cowpeas varied among genotypes, and ranged from 61 to 92 days in 2001, and from 65 to 99 days in 2002 when plants were grown under non-water-stressed conditions. Similar trends in maturity of cowpea genotypes were also found when plants were grown under water-stressed conditions. In the first experiment (2001), Quickpick Pinkeye and Elite were the early maturing genotypes (Table 2). Under the non-water-stressed conditions, Texas Cream 8, Mississippi Silver, Big Boy, Six Week Browneye and White Acre were of medium maturity, while California Blackeye 5, Champion and Two Crop Brown were late maturing. Under water-stressed conditions, Quickpick Pinkeye and Elite were early maturing genotypes, while the remaining genotypes were classified as medium to late maturity. In the second experiment (2002), the early maturing genotypes were also Elite and Quickpick Pinkeye, while the late maturity group included Champion, Two Crop Brown and California Blackeye 5. The other cowpea genotypes belonged to the medium maturity group. Water-stressed conditions in the 2002 growing season delayed the maturity of cowpea genotypes Quick Pinkeye, Mississippi Silver, Big Boy and Six Week Browneye by 2–10 days, while in the case of California Blackeye 5, Texas Cream 8, White Acre and Two Crop Brown crop maturities was earlier by 3–7 days. Maturity as given in the cultivar description (Table 1) was not a useful predictor of days to flowering or days to maturity in the present study. This could be due to differences in day length and other environmental conditions prevailing in the locations of breeding and where these tests were carried out.

Effects of water stress on seed yield, biological yield and harvest index of cowpeas

Cowpea genotypes grown under non-water-stressed conditions in both experiments (2001 and 2002) gave higher seed yield compared with the same genotypes grown under water-stressed conditions, except in the case of Six Week Browneye (Table 3). Under non-water-stressed conditions in the 2001 growing season, genotypes California Blackeye 5 and Champion significantly gave the highest seed yields, with California Blackeye 5 being the highest seed-yielding genotype (Table 3). On the contrary, lower seed yields were provided by genotypes White Acre and Big Boy. Other cowpea genotypes provided intermediate seed yields (Table 3).

When cowpeas were grown under water-stressed treatments in 2001, the highest seed yields were also provided by Champion and California Blackeye 5. Big boy had a seed yield lower than all genotypes, except White Acre and Mississippi Silver under water-stressed treatments.

Seed yield of cowpea genotypes grown under non-water-stressed conditions in the second experiment (2002) was also higher than the seed yield of the same genotypes that were grown under water-stressed conditions. Under non-water-stressed conditions, the highest seed-yielding genotypes were California Blackeye 5, Mississippi Silver and

Table 3: Seed yield and biological yield of cowpea genotypes under non-water-stressed and water-stressed conditions

Genotypes	Year 2001		Year 2002					
			Non-water-stressed			Water-stressed		
	Non-water-stressed seed yield (kg ha^{-1})	Water-stressed seed yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Quickpick Pinkeye	2756	1975	3806	7473	33.7	1927	4513	29.9
Elite	2156	1965	3308	13 445	19.7	1991	7050	22.0
Mississippi Silver	2666	1577	4588	9015	33.7	2320	7860	22.8
Six Week Browneye	1942	1969	3130	8981	25.8	2311	4992	31.6
Big Boy	1751	1322	3828	8223	31.8	2639	7160	26.9
Texas Cream 8	2732	1936	2560	11 710	17.9	1719	9773	15.0
White Acre	1515	1450	3373	14 213	19.2	1600	3373	32.2
Champion	3733	3024	3941	12 126	24.5	2035	4103	33.2
Two Crop Brown	2105	1888	3247	14 778	18.0	1988	5933	25.1
California Blackeye 5	4467	2561	4512	9399	32.4	2895	8068	26.4
LSD 0.05	343	477	360	2400	12.8	327	1642	16.3

Champion. Under water stress, California Blackeye 5 and Big Boy were the highest yielding lines, while White Acre was the lowest seed-yielding genotype.

Under non-water-stressed conditions in the 2002 growing season, Two Crop Brown, White Acre and Elite provided the highest biological yield (Table 3). This may suggest these three genotypes as useful candidates for seed production as cover crops. However, under water-stressed conditions, genotypes Texas Cream 8, California Blackeye 5 and Mississippi Silver gave high biological yields and may be the better genotypes for seed yield and cover cropping under water-stressed conditions.

The HI varied significantly among cowpea genotypes grown under non-water-stressed and water-stressed conditions. Genotypes with lower biological yields tended to have higher HI, and genotypes with higher biological yields tended to have lower HI. The HI of some cowpea genotypes such as California Blackeye 5 and Mississippi Silver was higher when plants were grown under non-water-stressed conditions than under water-stressed conditions. On the contrary, the HI of Champion and White Acre was higher when plants were grown under water-stressed conditions than those of other plants grown under non-water-stressed conditions.

Discussion

The most desirable cowpea genotype in the Delmarva region was California Blackeye 5 which was one of the highest seed-yielding genotypes in both growing seasons under the non-water stressed and water-stressed conditions of the present investigation. This may be due to the fact that California Blackeye 5 is resistant to diseases and pests such as root knot nematodes (*Meloidogyne* spp.), cowpea mosaic virus and *Fusarium* wilt (Kelly and NeSmith 1994, Ehlers and Hall 1997). Mississippi Silver and Champion were also identified by this study as high seed-yielding genotypes. Similarly, Mississippi Silver is resistant to cowpea mosaic virus, root knot nematodes (*Meloidogyne* spp.) and *Fusarium* wilt. Seed yield of California Blackeye 5 ranged from 4467 to 4512 kg ha^{-1} in the 2002 and 2001 experiments, respectively, under the non-water-stressed conditions. Under optimum condition in the United States, seed yields of cowpea up to 7000 kg ha^{-1} have been achieved in large field plots in some areas including the southern San Joaquin Valley of California (Sanden 1993). Under the conditions of the present study, the described plant growth habit did not appear related to HI nor to biological or seed yield. Days to maturity did not also appear to be related to seed yield, biological yield or HI. This is because cowpea cultivars tend to have narrow range of adaptation as cultivars developed for one zone usually are not very productive in other zones (Hall et al. 2003). However, in some of our previous field trials conducted in Maryland, cowpea genotypes such as California Blackeye 5 gave a 30–40 % increase in seed yield over the untreated plots by timely application of appropriate insecticides or by planting the crop 2–3 weeks earlier (Dadson et al. 2000). Clearly, there is a potential for further increase in seed yield by planting high-yielding genotypes, providing optimum irrigation, adding fertilizers (Singh 1987, Quin 1997, Singh et al. 1997), planting early and spraying with suitable insecticides.

Among the genotypes that provided the highest biological yield under non-water-stressed conditions in 2002 were Two Crop Browneye and White Acre, while under water-stressed conditions the highest biological yield was provided by Texas Cream 8 and California Blackeye 5 (Table 3). As the growth habits of these genotypes were bushy, prostrate or semi-erect these genotypes can be used as a cover crop as well as for grain. This confirms the finding that the spreading and bushy habits of cowpea genotypes provide superior ground cover, suppress weeds and provide some protection against soil erosion (Quin 1997). Cowpea is also used for green manure in southern USA (Ehlers and Hall 1997) and the spreading types with maximum biological yield could be used for soil improvement in this area. With its potential for high yield, cowpea could be introduced as an insurance crop on the Delmarva Peninsula which is prone to drought conditions. Moreover, the crop does not deplete the natural reserves of soil nitrogen. In fact, cowpea has the ability to fix substantial atmospheric nitrogen (Kuykendall et al. 2000, Hall et al. 2003), and thus increase the soil nitrogen by 40–80 kg N ha^{-1} (Quin 1997). The residues (stem, roots and leaves) also could contribute organic matter and associated nutrients to the soil.

The genotypes that provided the highest seed yields under water-stressed conditions such as California Blackeye 5 and Champion could serve as alternative crops because of their desirable attributes and resistance to major biotic and abiotic constraints, and this usually makes them suitable for different regions and cropping systems (Singh et al. 1997). Most of the genotypes in our experiments gave lower seed yield under water-stressed conditions than the seed yield of the same genotypes grown under non-water-stressed conditions. Although cowpea is considered to be a drought-resistant crop, failure of rainfall or lack of irrigation is a frequent cause of shortfall in production (Mortimore et al. 1997). Cowpea is primarily grown in dry areas, but drought is an important factor among several seed yield-reducing factors (Watanabe et al. 1997). Therefore, selection of cowpea genotypes that have higher tolerance to drought is needed to obtain higher and more stable seed yields for the Delmarva region.

Cowpea exhibits a wide range of plant habits, flowering times and maturities (Ehlers and Hall 1997). This study indicates that the early maturing cowpea genotypes for the Delmarva region were Quickpick Pinkeye and Elite while the late maturing genotypes were California Blackeye 5, Champion and Two Crop Brown. Earliness is an important agronomic trait that is typically measured by such criteria as days to maturity (Fery and Singh 1997). Earliness in maturity of cowpea genotypes is a desirable trait so that cowpeas can be grown in the niches of cereal-based cropping systems (Singh et al. 1997). The quick growth of cowpea is also desirable in drier areas where rainfall is scanty and soils are sandy with little organic matter (Singh et al. 1997). Early maturing cowpea cultivars have proved more useful in some dry environments and years because of their ability to escape drought (Hall and Patel 1985). The increased incidence of drought in some areas has caused a shift to early maturing varieties (Mortimore et al. 1997). In addition to escaping drought, early maturing cultivars can escape some insect infestations (Ehlers and Hall 1997).

The early erect type genotypes could be important for mechanized production to enable movement of farm machinery down the rows while cultivating, spraying pesticides and harvesting (Ehlers and Hall 1997). The cowpea growers in California harvest the crop either after the first flush is completed or after both first and second flushes are completed, mainly depending on the length of the growing season that is available for the crop (Hall and Frate 1996). In this study, all cowpea genotypes underwent three to four harvests manually. Synchronized maturity is also another desirable attribute that could be useful for mechanized cowpea production because it could facilitate efficient harvesting (Fery 1990) when cowpea will be adapted to large-scale production in the Delmarva region. Higher-yielding, drought-tolerant cultivars with early maturity would be desirable for production in the Delmarva Peninsula.

The growing season of 2002 was comparatively drier than the 2001 growing season. According to the UMES Weather Station, the rainfall was 30 % below normal conditions, and the air and soil temperatures were also higher than normal. These environmental factors might have negatively affected the growth of some of the cowpea genotypes as shown by Ehlers and Hall (1997) and Fery (1990), who reported that some cowpea genotypes were able to withstand the harsh drought conditions.

Therefore, the differences in seed yield within the same genotypes in the two seasons could have been due to the intensity and pattern of rainfall as well as elevated air and soil temperatures. Similar observations were reported by Koivisto et al. (2003) who stated that significant differences in soya bean performance in the two growing seasons was due to differences in the environmental conditions.

In conclusion, drought-resistant cowpea genotypes better suited to the Delmarva conditions could play an important role in filling the gap in the short fall of crop yields and sustain crop production in this region. The introduction of cowpea to the Delmarva region would enhance soil fertility and benefit corn and other cereal crops grown in rotation with it, thereby enhancing the sustainability of agriculture and the farming system of the Delmarva region. Cowpea could also be a valuable component of crop rotation in the Delmarva region due to the ability of resistant cultivars to suppress reproduction of root-knot nematodes, *Meloidogyne* spp. (Ehlers and Hall 1997) which infest the soya bean crop in the Delmarva region. It will also replenish soil nutrients through its symbiotic association with mycorrhizae and *Bradyrhizobium* spp. respectively (Kuykendall et al. 2000). This will limit the use of poultry manure and chemical fertilizers, thus decreasing the amount of phosphorus and nitrogen that leach into ground water and water bodies. This study supports our contention that cowpea could become a successful legume crop for the Delmarva region.

Acknowledgements

This project was supported by the CSREES Capacity Building Grant Program of USDA and the Agricultural Experiment Station at the University of Maryland Eastern Shore. The authors are grateful to these agencies for providing funding and the facilities, for the studies. The authors are also grateful to Dr. John Teasdale for his invaluable suggestions on the manuscript.

References

Alghali, A. M., 1991: Studies on the cowpea farming practices in Nigeria, with emphasis on insect pest control. Trop. Pest Manage. **37,** 71—74.

Anyia, A. O., and H. Herzog, 2004: Water-use efficiency, leaf area and leaf gas exchange of cowpeas under mid-season drought. Eur. J. Agron. **20,** 327—437.

Cisse, N., M. Ndiaye, S. Thiaw, and A. E., Hall, 1997: Registration of 'Melakh' cowpea. Crop Sci. **37,** 1978.

Dadson, R. B., I. Javaid, and J. M. Joshi, 2000: Sowing dates and insecticide sprays used to control cowpea insect pests, 143 pp. Annual meeting abstracts. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Minneapolis, Minnesota, USA. November 5—9.

Davis, D. W., D. B. Marsh, and M. N. Alvarez, 1986: Mn 13 and MN 150 Cowpea breeding lines. Hort. Sci. **21,** 1080—1081.

Dow El-Madina, I. M., and A. E. Hall, 1986: Flowering of contrasting cowpea (*Vigna unguiculata* L. Walp.) genotypes under different temperatures and photoperiods. Field Crops Res. **14,** 87—104.

Ehlers, J. D., and A. E. Hall, 1997: Cowpea (*Vigna unguiculata* L. Walp.). Field Crops Res. **53,** 187—204.

Elowed, H. O. A., and A. E. Hall, 1986: Influence of early and nitrogen fertilization on yield and nitrogen fixation of cowpea under well- watered and dry field conditions. Field Crops Res. **15,** 229—244.

Fery, R. L., 1990: The cowpea: production, utilization, and research in the United States. Hort. Rev. **12,** 197—222.

Fery R. L., and B. B. Singh, 1997: Cowpea genetics: a review of the recent literature. In: B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research, pp. 3—29. Co-publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Hall, A. E., and C. A. Frate, 1996: Blackeye Bean Production in California. Division of Agriculture and Natural Resources, Pub. no. 21518, University of California, Oakland, CA.

Hall, A. E., and P. N. Patel, 1985: Breeding for resistance to drought and heat. In: S. R. Singh, and K. O. Rachie, eds. Cowpea Research, Production and Utilization, pp. 137—151. Wiley, New York.

Hall, A. E., S. Thiaw, A. M. Ismail, and J. D. Ehlers, 1997: Water use efficiency and drought adaptations of cowpea. In: B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research, pp. 87—98. Co-publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Hall, A. E., N. Cisse, S. Thiaw, H. O. A. Elawadm, J. D. Ehlers, A. M. Ismail, R. L. Fery, P. A. Roberts, L. W. Kitch, L. L. Murdock, O. Boukar, R. D. Phillips, and K. H. McWatters, 2003: Development of cowpea cultivars and germ plasm by Bean/Cowpea CRSP. 2003. Field Crops Res. **82,** 103—134.

Ismail, A. M., and A. E. Hall, 1998: Positive and negative facts of heat tolerance genes studied using closely related cowpea lines. Crop Sci. **38,** 381—390.

Kelly, W. T., and D. S. NeSmith, 1994: Commercial Vegetable Variety Trials – Southern Peas. Vegetable

Facts, 4 pp. Cooperative Extension Service, Department of Horticulture, University of Georgia, Athens, GA.

Koivisto, J. M., T. E. Devine, G. P. E. Lane, S. E. Sawyer, and H. J. Brown, 2003: Forage soybeans (*Glycine max* (L.) Merr.) in the United Kingdom: test of new cultivars. Agronomie **23,** 287—291.

Kuykendall, L. D., F. M. Hashem, R. B. Dadson, and G. K. Elkan, 2000: Nitrogen fixation. In: J. Lederberg, ed. Encyclopedia of Microbiology, vol. 3, pp. 329—404. Academic Press, New York.

Kwapata, M. B., and A. E. Hall, 1985: Effects of moisture regime and phosphorus on mycorrhizal infection, nutrient uptake, and growth of cowpea (*Vigna unguiculata* (L.) Walp.). Field Crops Res. **12,** 241—250.

Martins, L. M. V., G. R. Xavier, F. W. Rangel, J. R. A. Ribeiro, M. C. P. Neves, L. B. Morgado, and N. G. Rumjanek, 2003: Contribution of biological fixation to cowpea: a strategy for improving seed yield in the semi-arid region of Brazil. Biol. Fertil. Soils **38,** 333—339.

Mortimore, M. J., B. B. Singh, F. Harris, and S. F. Balde, 1997: Cowpea in traditional cropping systems. In: B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, (eds). Advances in Cowpea Research, pp. 99—113. Co-publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Nielsen, C. L., and E. Hall, 1985: Responses of cowpea (*Vigna unguiculata* (L). Walp.) in the field to high night air temperature during flowering 11. Plant responses. Field Crops Res. **10,** 181—191.

Oghiakhe, S., L. L. E. N. Jackai, and W. A. Makanjuola, 1995: Evaluation of cowpea genotypes for field resistance to legume pod borer, *Maruca testulalis*, in Nigeria. Crop Prot. **14,** 389—394.

Patel, P. N., and A. E. Hall, 1990: Genotypes variation and classification of cowpea for reproductive responses to high temperatures under long photoperiods. Crop Sci. **30,** 614—621.

Quin, F. M., 1997: Introduction. In: B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research, pp. ix—xv. Co-publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Sanden, B., 1993: Blackeye Varietals and Irrigation Cut Off Trial. Univ. California Dry Bean Research – 1993 Prog. Rep. pp. 120—121. California Dry Bean Advisory Board, Dinuba, CA.

Singh, B. B., 1987: Breeding cowpea varieties for drought escape. In: J. M. Menyonga, T. Bezuneh, and A. Youdeowei, eds. Food Seed Production in Semi Arid Africa, pp. 299—306. OAU/STRC- SAFGRAD, Ouagadougou, Burkina Faso.

Singh, B. B., O. L. Chambliss, and B. Sharma, 1997: Recent advances in cowpea breeding. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research, pp. 114—128. Co-publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Steel, R. G. B., and J. H. Torrie, 1980: Principles and Procedures of Statistics. McGraw-Hill, New York.

US Department of Agriculture, 1996: Agricultural Statistics. Govt. Printing Office, Washington, DC.

USDA, 1978: Delmarva River Basins Cooperative Survey Vol. 2, pp. 1—11. United States Department of Agriculture and the States of Delware, Maryland and Virginia, USA.

Watanabe, I., S. Hakoyama, T. Terao, and B. B. Singh, 1997: Evaluation method for tolerance of cowpea. In: B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research, pp. 141—146. Co-publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Wendt, W. C., J. E. Quisenberry, W. O. Phillips, L. J. Mabry, and B. L. Stuart, 1981: Response of cotton cultivar T25 with fruiting habit to irrigation. In: Proceedings Beltwide Cotton Production Research Conference, 4—8 Jan. 1981, New Orleans, p. 44. National Cotton Council of America, Memphis, TN.

Wilcox, J., 2004: World distribution and trade of soybean. In: R. M. Shibles, J. E. Harper, R. F. Wilson, and R. C. Shoemaker, eds. Soybeans Improvement, Production, and Uses, 3rd edn, pp. 1—14. Agronomy no. 16. ASA, CSSA, SSSA, Madison, WI.